Chirp and Click Evoked Auditory Steady State Responses

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***Abstract-* In this study, Auditory Steady State Responses (ASSR) to 100 µsec clicks and 4 msec cochlear chirps are recorded in adult subjects at repetition rates of 20 to 100 Hz in 10 Hz increments. Response characteristics of ASSRs are compared in the frequency domain. Results show that response amplitudes to both stimuli peak in the proximity of 40 Hz and 80 Hz, but chirps generate responses with larger amplitudes at all repetition rates. The responses at 40 Hz repetition rates for both clicks and chirps are larger than the corresponding responses at 80 Hz stimuli in awake adults. The 40 Hz responses, however, show greater variability than the 80 Hz responses depending on the subject's state of consciousness. The predictions of the ASSR waveforms at each repetition rate were then synthesized by superimposing the suitably shifted Middle Latency Response (MLR) waveforms that were recorded during the same session with a stimulus repetition rate of 10 Hz for both click and chirp recordings. This part of the study was undertaken to investigate the validity of the hypothesis which states that the steady state responses are simply the linear additions of transient MLRs. The results showed that the synthesized waveforms resembled the real recordings to some extent, but consistently had larger amplitudes. This difference is assumed to be a result of the adaptation effects of higher stimulus rates.**
***Keywords:* Steady-State Responses, Auditory Evoked Potentials, chirp stimuli, adaptation**

1. INTRODUCTION

Hearing evaluation of patients who are unable to provide reliable behavioral responses is a major concern for audiologists and hearing scientists because conventional behavioral hearing testing relies heavily on the ability and willingness of the subject to give a response. Auditory assessment is especially important in early detection, diagnosis, and audiological management of hearing impaired children, where early intervention has significant benefits for the development of speech, and language skills in the long term [1,2]. Auditory evoked potentials (AEP) are the electrical potentials generated within the auditory system when the system is stimulated with sounds. AEPs are among today's most useful tools for objective evaluation of the auditory system.

Auditory evoked potentials can be classified as transient responses or steady state responses. Transient responses are evoked by stimuli presented at such a slow rate that the response to one stimulus is finished before the response to the next stimulus occurs. Steady state responses, however, are evoked when stimuli are presented at a sufficiently high rate causing an overlapping of the responses to successive stimuli [3]. This overlapping results in a periodic response with a constant frequency and a constant phase relation to the repeating stimulus, therefore referred to as steady state responses (SSR).

Auditory steady-state response (ASSR) recording has gained popularity in recent years. Different stimulus types are being used for evoking these periodic scalp potentials: Clicks or tone-bursts presented at sufficiently high rates, and regularly varying stimuli such as sinusoidal amplitude modulated (AM) and/or frequency modulated (FM) tones are also being used successfully [4, 5, 6, 7, 8, 9,10, 11].

An acoustic sinusoidal signal with a continuously changing instantaneous frequency is called a chirp. This relatively new stimulus type in evoked potential studies, has been used in auditory brainstem response [12], and otoacoustic emission [13] studies successfully. It has been shown in those studies that the chirp stimulus was able to evoke better responses with better-synchronized firing of the auditory neurons than click stimulus.

In this study, we used rising-frequency chirp stimulus designed for compensating the traveling wave velocity differences in the cochlea according to the DeBoer's cochlear model [14] in order to determine if it will generate better ASSR.

We also attempted to simulate the ASSR recordings by superimposing the appropriately shifted AEP waveforms consisting of Auditory Brainstem Response (ABR) and Middle Latency Responses (MLR) in order to see how well the linear addition of individual responses models the generation of SSRs.

2. METHODS AND INSTRUMENTATION

2.1 Recording Set-up and Parameters

The stimuli utilized in this study were 100 µsec clicks and 4 msec chirps (.4 to 8kHz) presented at rates from 10 Hz to 100 Hz in 10 Hz steps. Both stimuli had the same peak equivalent sound pressure levels (90 peSPL). The chirp stimulus used in this study was generated so that it theoretically compensates for the travel time delay along the cochlear partition [12] resulting in simultaneous displacement of a large portion of the basilar membrane.

The system designed for stimulus generation and data acquisition was based on a microcomputer-based evoked potential system (Smart-EP, Intelligent Hearing Systems,

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Miami, FL) which uses a digital signal processor (TMS320C31). Both click and chirp stimuli were synthesized digitally on an IBM-compatible personal computer, converted to the analog domain with a 14 bit digital-to-analog (D/A) converter, and delivered to the subject using ER-3A insert earphones (Etymotic Research, Elk Grove Village, IL). The recording window length was set to 500 msec (5000 data points) for each recording.

Responses were recorded from the scalp using gold cup electrodes placed at the midline forehead (positive), the ipsilateral mastoid (negative), and the contralateral mastoid (ground). The signals were amplified 100,000 times with a differential amplifier (Opti-Amp3000D, Intelligent Hearing Systems, Miami, FL), and band-pass filtered (high-pass: 3 Hz, low-pass: 3000 Hz; 6 dB cut-off points with 6 dB/octave slopes). The filter settings used were chosen to enable the recording of both transient (ABR, MLR), and steady state responses. The amplified signals were digitized with a 16 bit analog-to-digital (A/D) converter with a sampling rate of 10 kHz. The stimuli were delivered continuously, and each recording consisted of two buffers, one for odd numbered sweeps and one for even numbered sweeps. The buffers were used for averaging 128 sweeps each, and then the resulting averages were stored digitally on the computer. The artifact rejection level was set to 50 µVolts.

A total of 11 ears from 9 normal hearing young adult subjects (5 male, 4 female) were tested in this study. The subjects were between 17 and 28 years old. All recordings were done in a sound-treated chamber (Acoustic Systems, Inc) with subjects lying on a bed resting.

2.2 Analysis and Modelling

All analysis was done off-line using MATLAB software (Mathworks, Inc.). The recorded responses were analyzed both in the time domain (ABR and MLR) and the frequency domain (ASSR). The frequency domain information was obtained with the use of a 5,000-point DFT, which resulted in a frequency resolution of 2 Hz.

The difference between the click and chirp evoked ABR and MLR waveforms were investigated by looking at the recordings obtained at 10 Hz repetition rate. Typical responses obtained for both clicks and chirps from a subject are presented in Fig.1. The major peaks (V and P_a) are identified and amplitude measurements are shown.

The 10 Hz recordings from each subject were used to simulate the SSRs at other repetition rates by putting each one into a circular buffer, and shifting and averaging several responses. The shifting times used were 50, 33.3, 25, 20, 16.6, 14.2, 11.1, and 10 msec for 20, 30, 40, 50, 60, 70, 80, 90, and 100 Hz data, respectively. For example, in order to simulate the 20 Hz SSR, the original 10 Hz signal

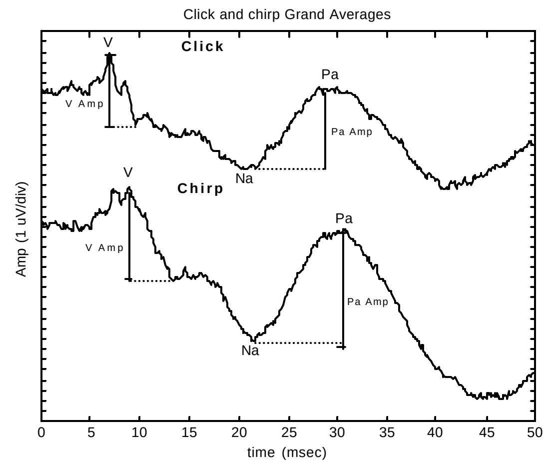

Fig. 1 Click (top) and chirp (bottom) evoked ABR and MLR waveforms from a young female subject. The time scale is not compensated for the 1 msec delay caused by the acoustic stimulus delivery.

was shifted 50 msec, and then added to the original one. To simulate the 40 Hz signal, the original was shifted 25 msec repeatedly for three times, and the resulting three shifted waveforms are averaged with the original.

3. RESULTS

Transient auditory evoked responses, and auditory steady-state responses to click and chirp stimuli with different repetition rates have been studied, and chirp stimulus has been shown to generate higher response levels in comparison with click stimulus. As shown in Fig. 1, chirp evoked ABRs have on average 15% larger Wave V, and 40% larger P_a amplitudes. The chirp responses have longer latencies, and somewhat different morphologies as can be seen in Fig. 1.

Fig. 2 displays a sample ASSR recording from a female subject using click and chirp stimuli with 70 Hz repetition

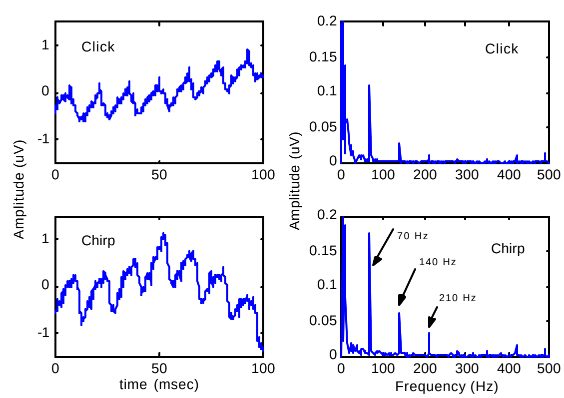

Fig. 2 Sample ASSR recordings from a subject in the time domain (left) and the frequency domain (right). The click (top) and chirp (bottom) stimuli were both presented at 70 Hz repetition rate. In addition to the main frequency component at 70 Hz, the second and third harmonics are also observed.

rate. This recording shows much bigger components for chirp recordings at 70 Hz, 140 Hz, and 210 Hz which correspond to the first, second, and third harmonics of the steady state response.

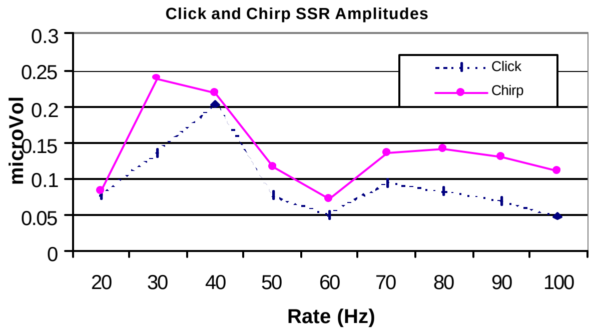

Fig. 3 The comparison of click and chirp evoked auditory steady state response amplitudes at different repetition rates. Average data from 11 subjects.

Fig. 3 shows the values of the amplitude spectrum at the stimulation frequency bin of the click and chirp evoked steady state responses for different stimulus repetition rates. Both responses follow a similar pattern having peaks around the 40 Hz and 80 Hz region. It is clearly observed that the 40 Hz region peak is much higher for both click and chirp cases. The chirp evoked responses are bigger than the click evoked responses at all repetition rates.

Fig. 4 and Fig. 5 compare the real and simulated steady state responses for click and chirp stimuli, respectively. As can be seen from Fig. 4, the simulated click SSR amplitudes are higher than the corresponding real ones at all levels, but thay follow the pattern: both have peaks around 40 Hz. The simulated amplitudes overshoot at 90 and 100 Hz repetition rates. The similar pattern is observed in Fig. 5 for the chirp evoked SSRs.

4. DISCUSSION

The generation mechanisms of the steady-state responses are still a topic of debate that has not reached a full consensus yet. One of the simplest and most plausible hypotheses suggests that the steady state responses are simply the linear superposition of transient evoked potentials (ABR, and MLR) that are evoked by individual stimuli [3]. Although this hypothesis was shown to be effective by some authors [3, 15], other studies suggest that it does not fully explain all aspects of the SSRs in an effective way [16, 17]. We tested this hypothesis with our data for both click and chirp stimuli at different rates. As depicted in Fig. 4 and Fig. 5, the simulations yielded a similar general trend in the SSR amplitudes, but the simulation amplitudes were larger than recorded amplitudes at most repetition rates. This can be partially explained by adaptation effects and the shortcomings of the averaging of the same responses used in this study. This reasoning,

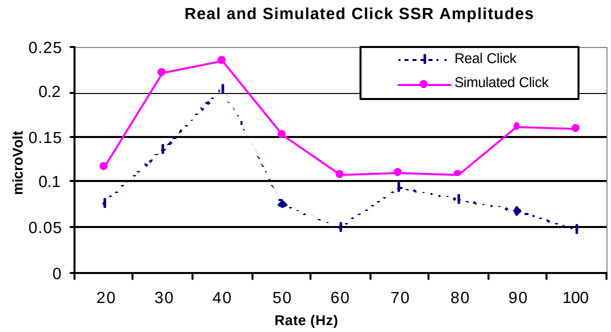

Fig. 4 Comparison of simulated and real click evoked auditory steady state responses. The simulated waveform amplitudes follow the same pattern for most of the time, but they are larger then their real counterparts.

however, does explain the subtle differences observed between simulation and real responses at higher repetition rates (70-100 Hz). Different adaptation of the fast and slow components of ABRs [18], nonlinearities and resonance phenomena [19] may play important roles in explaining such differences.

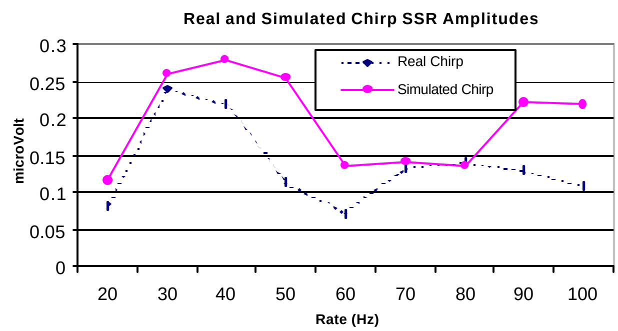

Fig. 5 Comparison of simulated and real chirp evoked auditory steady state responses.

5. CONCLUSION

Auditory steady-state responses to chirp stimuli can be recorded and detected reliably. Chirp evoked ASSRs have larger amplitudes than click evoked ASSRs due to presumably better synchronization of the firing of a larger population of neural components. This yields a better signal-to-noise ratio, and improves the detectability of the responses.

Even though simple summations of transient responses by linear shifting at appropriate rates explain the main characteristics of the chirp and click evoked ASSRs, they fail to describe all of the properties observed especially at high repetition rates. Adaptation effects of the increasing stimulus rate on the ABR and MLR components should be incorporated into a more complete model to explain the ASSR generation using the overlapping of transient responses. Such a model should use different adaptation rates for different evoked potential components. This comprehensive model may further elucidate the role played by other proposed mechanisms such as the resonance phenomena.

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